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EMF Controversies in Neurobiology

Controversies on Electromagnetic Fields in Neurobiology of Organisms

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Süleyman Kaplan, Devra Davis. [Editorial](#). Pages 41-42

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Martin L. Pall. [Microwave frequency electromagnetic fields \(EMFs\) produce widespread neuropsychiatric effects including depression](#). Review Article. Pages 43-51.

Highlights

- Microwave EMFs activate voltage-gated Ca²⁺ channels (VGCCs) concentrated in the brain.
- Animal studies show such low level MWV EMFs have diverse high impacts in the brain.
- VGCC activity causes widespread neuropsychiatric effects in humans (genetic studies).
- 26 studies have EMFs assoc. with neuropsychiatric effects; 5 criteria show causality.
- MWV EMFs cause at least 13 neuropsychiatric effects including depression in humans.

Abstract

Non-thermal microwave/lower frequency electromagnetic fields (EMFs) act via voltage-gated calcium channel (VGCC) activation. Calcium channel blockers block EMF effects and several types of additional evidence confirm this mechanism. Low intensity microwave EMFs have been proposed to produce neuropsychiatric effects, sometimes called microwave syndrome, and the focus of this review is whether these are indeed well documented and consistent with the known mechanism(s) of action of such EMFs. VGCCs occur in very high densities throughout the nervous system and have near universal roles in release of neurotransmitters and neuroendocrine hormones. Soviet and Western literature shows that much of the impact of non-thermal microwave exposures in experimental animals occurs in the brain and peripheral nervous system, such that nervous system histology and function show diverse and substantial changes. These may be generated through roles of VGCC activation, producing excessive neurotransmitter/neuroendocrine release as well as oxidative/nitrosative stress and other responses. Excessive VGCC activity has been shown from genetic polymorphism studies to have roles in producing neuropsychiatric changes in humans. Two U.S. government reports from the 1970s to 1980s provide evidence for many neuropsychiatric effects of non-thermal microwave EMFs, based on occupational exposure studies. 18 more recent epidemiological studies, provide substantial evidence that microwave EMFs from cell/mobile phone base stations, excessive cell/mobile phone usage and from wireless smart meters can each produce similar patterns of neuropsychiatric effects, with several of these studies showing clear dose–response relationships. Lesser evidence from 6 additional studies suggests that short wave, radio station, occupational and digital TV antenna exposures may produce similar neuropsychiatric effects. Among the more commonly reported changes are sleep disturbance/insomnia, headache, depression/depressive symptoms, fatigue/tiredness, dysesthesia, concentration/attention dysfunction, memory changes, dizziness, irritability, loss of appetite/body weight, restlessness/anxiety, nausea, skin burning/ tingling/ dermatographism and EEG changes. In summary, then, the mechanism of action of microwave EMFs, the role of the VGCCs in the brain, the impact of non-thermal EMFs on the brain, extensive epidemiological studies performed over the past 50 years, and five criteria testing for

causality, all collectively show that various non-thermal microwave EMF exposures produce diverse neuropsychiatric effects.

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Suleyman Kaplan, Omur Gulsum Deniz, Mehmet Emin Önger, Aysin Pinar Türkmen, Kıymet Kübra Yurt, Işinsu Aydın, Berrin Zuhail Altunkaynak, Devra Davis. [Electromagnetic field and brain development](#). Review Article. Pages 52-61.

Highlights

- Side effects of electromagnetic field.
- How electromagnetic field affects the brain development?
- Experimental and clinical studies about the electromagnetic field.

Abstract

Rapid advances in technology involve increased exposures to radio-frequency/microwave radiation from mobile phones and other wireless transmitting devices. As cell phones are held close to the head during talking and often stored next to the reproductive organs, studies are mostly focused on the brain. In fact, more research is especially needed to investigate electromagnetic field (EMF)'s effects on the central nervous system (CNS). Several studies clearly demonstrate that EMF emitted by cell phones could affect a range of body systems and functions. Recent work has demonstrated that EMF inhibit the formation and differentiation of neural stem cells during embryonic development and also affect reproductive and neurological health of adults that have undergone prenatal exposure. The aim of this review is to discuss the developing CNS and explain potential impacts of EMF on this system.

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Berrin Zuhail Altunkaynak, Gamze Altun, Ahmed Yahyazadeh, Arife Ahsen Kaplan, Omur Gulsum Deniz, Aysin Pinar Türkmen, Mehmet Emin Önger, Suleyman Kaplan. [Different methods for evaluating the effects of microwave radiation exposure on the nervous system](#). Review Article. Pages 62-69.

Highlights

- Overview to different frequencies of electromagnetic field radiation exposure.
- Possible side effects of microwave radiation on the central nervous system.
- Qualitative and quantitative analysis to reveal the effects of the electromagnetic field exposure.

Abstract

Microwave radiation (MWR) leads to hazardous effects on the central nervous system (CNS) for both human and animals. The widespread use of mobile phones has increased the risks of health problems in the CNS caused by radiofrequency (RF) electromagnetic fields. To determine these effects various methodological approaches related to neuroscience such as stereology, immunohistochemistry, and electron microscopy have been used. These approaches examine the effects on cells exposed to MWR at the light microscopic and ultrastructural levels, and novel information is obtained. The main aim of this paper is to discuss possible side effects of MWR in the light of current literature with different methodological approaches.

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Ferhat Say, Berrin Zuhale Altunkaynak, Sina Coşkun, Ömür Gülsüm Deniz, Çağrı Yıldız, Gamze Altun, Arife Ahsen Kaplan, Sefa Ersan Kaya, Ahmet Pişkin. [Controversies related to electromagnetic field exposure on peripheral nerves](#). Review Article. Pages 70-76.

Highlights

- Possible effects of electromagnetic field.
- How electromagnetic field affects the peripheral nerve structure?
- Experimental and clinical studies of nervous system on the electromagnetic field.

Abstract

Electromagnetic field (EMF) is a pervasive environmental presence in modern society. In recent years, mobile phone usage has increased rapidly throughout the world. As mobile phones are generally held close to the head while talking, studies have mostly focused on the central and peripheral nervous system. There is a need for further research to ascertain the real effect of EMF exposure on the nervous system. Several studies have clearly demonstrated that EMF emitted by cell phones could affect the systems of the body as well as functions. However, the adverse effects of EMF emitted by mobile phones on the peripheral nerves are still controversial. Therefore, this review summarizes current knowledge on the possible positive or negative effects of electromagnetic field on peripheral nerves.

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Murat Terzi, Berra Ozberk, Omur Gulsum Deniz, Suleyman Kaplan. [The role of electromagnetic fields in neurological disorders](#). Review Article. Pages 77-84.

Highlights

- Description of electromagnetic fields and evaluation of its possible effects on biological systems.
- The association between the electromagnetic field and neurodegenerative diseases.
- Experimental and clinical studies on the electromagnetic field.

Abstract

In the modern world, people are exposed to electromagnetic fields (EMFs) as part of their daily lives; the important question is "What is the effect of EMFs on human health?" Most previous studies are epidemiological, and we still do not have concrete evidence of EMF pathophysiology. Several factors may lead to chemical, morphological, and electrical alterations in the nervous system in a direct or indirect way. It is reported that non-ionizing EMFs have effects on animals and cells. The changes they bring about in organic systems may cause oxidative stress, which is essential for the neurophysiological process; it is associated with increased oxidation in species, or a reduction in antioxidant defense systems. Severe oxidative stress can cause imbalances in reactive oxygen species, which may trigger neurodegeneration. This review aims to detail these changes. Special attention is paid to the current data regarding EMFs' effects on neurological disease and associated symptoms, such as headache, sleep disturbances, and fatigue.

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Suleyman Dasdag, Mehmet Zulkuf Akdag. [The link between radiofrequencies emitted from wireless technologies and oxidative stress](#). Review Article. Pages 85-93.

Abstract

Wireless communication such as cellular telephones and other types of handheld phones working with frequencies of 900 MHz, 1800 MHz, 2100 MHz, 2450 MHz have been increasing rapidly. Therefore, public opinion concern about the potential human health hazards of short and long-term

effect of exposure to radiofrequency (RF) radiation. Oxidative stress is a biochemical condition, which is defined by the imbalance between reactive oxygen species (ROS) and the anti-oxidative defense. In this review, we evaluated available in vitro and in vivo studies carried out on the relation between RF emitted from mobile phones and oxidative stress. The results of the studies we reviewed here indicated that mobile phones and similar equipment or radars can be thought as a factor, which cause oxidative stress. Even some of them claimed that oxidative stress originated from radiofrequencies can be resulted with DNA damage. For this reason one of the points to think on is relation between mobile phones and oxidative stress. However, more performance is necessary especially on human exposure studies.

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Duygu Sahin, Elcin Ozgur, Goknur Guler, Arin Tomruk, Ilhan Unlu, Aylin Sepici-Dinçel, Nesrin Seyhan. [The 2100 MHz radiofrequency radiation of a 3G-mobile phone and the DNA oxidative damage in brain](#). Pages 94-98.

Highlights

- The 2100 MHz radiofrequency radiation and oxidative DNA damage in brain.
- The effects of duration and tissue type to DNA damage.

Abstract

We aimed to evaluate the effect of 2100 MHz radiofrequency radiation emitted by a generator, simulating a 3G-mobile phone on the brain of rats during 10 and 40 days of exposure. The female rats were randomly divided into four groups. Group I; exposed to 3G modulated 2100 MHz RFR signal for 6 h/day, 5 consecutive days/wk for 2 weeks, group II; control 10 days, were kept in an inactive exposure set-up for 6 h/day, 5 consecutive days/wk for 2 weeks, group III; exposed to 3G modulated 2100 MHz RFR signal for 6 h/day, 5 consecutive days/wk for 8 weeks and group IV; control 40 days, were kept in an inactive exposure set-up for 6 h/day, 5 consecutive days/wk for 8 weeks. After the genomic DNA content of brain was extracted, oxidative DNA damage (8-hydroxy-2'deoxyguanosine, pg/mL) and malondialdehyde (MDA, nmol/g tissue) levels were determined. Our main finding was the increased oxidative DNA damage to brain after 10 days of exposure with the decreased oxidative DNA damage following 40 days of exposure compared to their control groups. Besides decreased lipid peroxidation end product, MDA, was observed after 40 days of exposure. The measured decreased quantities of damage during the 40 days of exposure could be the means of adapted and increased DNA repair mechanisms.

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İkinci, Tolga Mercantepe, Deniz Unal, Hüseyin Serkan Erol, Arzu Şahin, Ali Aslan, Orhan Baş, Havva Erdem, Osman Fikret Sönmez, Haydar Kaya, Ersan Odacı. [Morphological and antioxidant impairments in the spinal cord of male offspring rats following exposure to a continuous 900 MHz electromagnetic field during early and mid-adolescence](#). Pages 99-104.

Highlights

- Spinal cords of male rats were investigated following exposure to 900 MHz EMF.
- Tissue malondialdehyde and glutathione levels increased in the EMF group.
- Light microscopy revealed atrophy in the spinal cord in the EMF group.
- TEM revealed invagination into the axon in the EMF group.
- TEM revealed loss of myelin sheath integrity in the EMF group.

Abstract

The effects of devices emitting electromagnetic field (EMF) on human health have become the subject of intense research among scientists due to the rapid increase in their use. Children and adolescents are particularly attracted to the use of devices emitting EMF, such as mobile phones. The aim of this study was therefore to investigate changes in the spinal cords of male rat pups exposed to the effect of 900 MHz EMF. The study began with 24 Sprague-Dawley male rats aged 3 weeks. Three groups containing equal numbers of rats were established—control group (CG), sham group (SG) and EMF group (EMFG). EMFG rats were placed inside an EMF cage every day between postnatal days (PD) 21 and 46 and exposed to the effect of 900 MHz EMF for 1 h. SG rats were kept in the EMF cage for 1 h without being exposed to the effect of EMF. At the end of the study, the spinal cords in the upper thoracic region of all rats were removed. Tissues were collected for biochemistry, light microscopy (LM) and transmission electron microscopic (TEM) examination. Biochemistry results revealed significantly increased malondialdehyde and glutathione levels in EMFG compared to CG and SG, while SG and EMFG catalase and superoxide dismutase levels were significantly higher than those in CG. In EMFG, LM revealed atrophy in the spinal cord, vacuolization, myelin thickening and irregularities in the perikarya. TEM revealed marked loss of myelin sheath integrity and invagination into the axon and broad vacuoles in axoplasm. The study results show that biochemical alterations and pathological changes may occur in the spinal cords of male rats following exposure to 900 MHz EMF for 1 h a day on PD 21–46.

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Ersan Odacı, Hatice Hancı, Ayşe İkinci, Osman Fikret Sönmez, Ali Aslan, Arzu Şahin, Haydar Kaya, Serdar Çolakoglu, Orhan Baş. [Maternal exposure to a continuous 900-MHz electromagnetic field provokes neuronal loss and pathological changes in cerebellum of 32-day-old female rat offspring](#) Pages 105-110.

Highlights

- The female rat pup cerebellum was investigated following prenatal 900 MHz EMF exposure.
- Total Purkinje cell numbers were estimated following prenatal 900 MHz EMF exposure.
- Purkinje cell numbers were lower in the EMF group compared to the control and sham groups.
- Pyknotic neurons with dark cytoplasm were observed in the EMF group.

Abstract

Large numbers of people are unknowingly exposed to electromagnetic fields (EMF) from wireless devices. Evidence exists for altered cerebellar development in association with prenatal exposure to EMF. However, insufficient information is still available regarding the effects of exposure to 900 megahertz (MHz) EMF during the prenatal period on subsequent postnatal cerebellar development. This study was planned to investigate the 32-day-old female rat pup cerebellum following exposure to 900 MHz EMF during the prenatal period using stereological and histopathological evaluation methods. Pregnant rats were divided into control, sham and EMF groups. Pregnant EMF group (PEMFG) rats were exposed to 900 MHz EMF for 1 h inside an EMF cage during days 13–21 of pregnancy. Pregnant sham group (PSG) rats were also placed inside the EMF cage during days 13–21 of pregnancy for 1 h, but were not exposed to any EMF. No procedure was performed on the pregnant control group (PCG) rats. Newborn control group (CG) rats were obtained from the PCG mothers, newborn sham group (SG) rats from the PSG and newborn EMF group (EMFG) rats from the PEMFG rats. The cerebellums of the newborn female rats were extracted on postnatal day 32. The number of Purkinje cells was estimated stereologically, and histopathological evaluations were also performed on cerebellar sections. Total Purkinje cell numbers calculated using stereological analysis were significantly lower in EMFG compared to CG ($p < 0.05$) and SG ($p < 0.05$). Additionally, some pathological changes such as pyknotic neurons with dark cytoplasm were observed in EMFG sections under light microscopy. In conclusion, our study results show that prenatal exposure to EMF

affects the development of Purkinje cells in the female rat cerebellum and that the consequences of this pathological effect persist after the postnatal period.

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Arda Esmekaya, Mehmet Zahid Tuysuz, Arın Tomruk, Ayse G. Canseven, Engin Yücel, Zuhail Aktuna, Semih Keskil, Nesrin Seyhan. [Effects of cell phone radiation on lipid peroxidation, glutathione and nitric oxide levels in mouse brain during epileptic seizure](#). Pages 111-115.

Abstract

The objective of this study was to evaluate the effects of cellular phone radiation on oxidative stress parameters and oxide levels in mouse brain during pentylenetetrazole (PTZ) induced epileptic seizure. Eight weeks old mice were used in the study. Animals were distributed in the following groups: Group I: Control group treated with PTZ, Group II: 15 min cellular phone radiation + PTZ treatment + 30 min cellular phone radiation, Group III: 30 min cellular phone radiation + PTZ treatment + 30 min cellular phone radiation. The RF radiation was produced by a 900 MHz cellular phone. Lipid peroxidation, which is the indicator of oxidative stress was quantified by measuring the formation of thiobarbituric acid reactive substances (TBARS). The glutathione (GSH) levels were determined by the Ellman method. Tissue total nitric oxide (NOx) levels were obtained using the Griess assay. Lipid peroxidation and NOx levels of brain tissue increased significantly in group II and III compared to group I. On the contrary, GSH levels were significantly lower in group II and III than group I. However, no statistically significant alterations in any of the endpoints were noted between group II and Group III. Overall, the experimental findings demonstrated that cellular phone radiation may increase the oxidative damage and NOx level during epileptic activity in mouse brain.

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Mehmet Zulkuf Akdag, Suleyman Dasdag, Fazile Canturk, Derya Karabulut, Yusuf Caner, Nur Adalier. [Does prolonged radiofrequency radiation emitted from Wi-Fi devices induce DNA damage in various tissues of rats?](#) Pages 116-122.

Abstract

Wireless internet (Wi-Fi) providers have become essential in our daily lives, as wireless technology is evolving at a dizzying pace. Although there are different frequency generators, one of the most commonly used Wi-Fi devices are 2.4 GHz frequency generators. These devices are heavily used in all areas of life but the effect of radiofrequency (RF) radiation emission on users is generally ignored. Yet, an increasing share of the public expresses concern on this issue. Therefore, this study intends to respond to the growing public concern. The purpose of this study is to reveal whether long term exposure of 2.4 GHz frequency RF radiation will cause DNA damage of different tissues such as brain, kidney, liver, and skin tissue and testicular tissues of rats. The study was conducted on 16 adult male Wistar–Albino rats. The rats in the experimental group (n = 8) were exposed to 2.4 GHz frequency radiation for over a year. The rats in the sham control group (n = 8) were subjected to the same experimental conditions except the Wi-Fi generator was turned off. After the exposure period was complete the possible DNA damage on the rat's brain, liver, kidney, skin, and testicular tissues was detected through the single cell gel electrophoresis assay (comet) method. The amount of DNA damage was measured as percentage tail DNA value. Based on the DNA damage results determined by the single cell gel electrophoresis (Comet) method, it was found that the % tail DNA values of the brain, kidney, liver, and skin tissues of the rats in the experimental group increased more than those in the control group. The increase of the DNA damage in all tissues was not significant ($p > 0.05$). However the increase of the DNA damage in rat testes tissue was significant ($p < 0.01$). In conclusion, long-term exposure to 2.4 GHz RF radiation (Wi-Fi) does not cause DNA damage of the organs investigated in this study except testes. The results of this study indicated that testes are more sensitive organ to RF radiation.

Bahriye Sirav, Nesrin Seyhan. [Effects of GSM modulated radio-frequency electromagnetic radiation on permeability of blood–brain barrier in male & female rats](#). Pages 123-127.

Highlights

- Exposure to the pulse modulated radio-frequency radiation could lead to increase in the permeability of blood–brain barrier.
- New researches are needed to discuss the effects of radio-frequency radiation on children.
- Efforts have to be made to understand the mechanisms of the interaction of radio-frequency radiation and the central nervous system.

Abstract

With the increased use of mobile phones, their biological and health effects have become more important. Usage of mobile phones near the head increases the possibility of effects on brain tissue. This study was designed to investigate the possible effects of pulse modulated 900 MHz and 1800 MHz radio-frequency radiation on the permeability of blood–brain barrier of rats. Study was performed with 6 groups of young adult male and female wistar albino rats. The permeability of blood-brain barrier to intravenously injected evans blue dye was quantitatively examined for both control and radio-frequency radiation exposed groups. For male groups; Evans blue content in the whole brain was found to be 0.08 ± 0.01 mg% in the control, 0.13 ± 0.03 mg% in 900 MHz exposed and 0.26 ± 0.05 mg% in 1800 MHz exposed animals. In both male radio-frequency radiation exposed groups, the permeability of blood–brain barrier found to be increased with respect to the controls ($p < 0.01$). 1800 MHz pulse modulated radio-frequency radiation exposure was found more effective on the male animals ($p < 0.01$). For female groups; dye contents in the whole brains were 0.14 ± 0.01 mg% in the control, 0.24 ± 0.03 mg% in 900 MHz exposed and 0.14 ± 0.02 mg% in 1800 MHz exposed animals. No statistical variance found between the control and 1800 MHz exposed animals ($p > 0.01$). However 900 MHz pulse modulated radio-frequency exposure was found effective on the permeability of blood-brain barrier of female animals. Results have shown that 20 min pulse modulated radio-frequency radiation exposure of 900 MHz and 1800 MHz induces an effect and increases the permeability of blood-brain barrier of male rats. For females, 900 MHz was found effective and it could be concluded that this result may due to the physiological differences between female and male animals. The results of this study suggest that mobile phone radiation could lead to increase the permeability of blood-brain barrier under non-thermal exposure levels. More studies are needed to demonstrate the mechanisms of that breakdown.

Göknur Güler, Elcin Ozgur, Hikmet Keles, Arin Tomruk, Sevil Atalay Vural, Nesrin Seyhan. [Neurodegenerative changes and apoptosis induced by intrauterine and extrauterine exposure of radiofrequency radiation](#). Pages 128-133.

Highlights

- Fetal exposure to mobile phone radiation causes apoptosis and oxidative damage in brain.

Abstract

Adverse health effects of radiofrequency radiation (RFR) on the ongoing developmental stages of children from conception to childhood are scientifically anticipated subject. This study was performed to identify the effects of global system for mobile communications (GSM) modulated mobile phone like RFR in 1800 MHz frequency on oxidative DNA damage and lipid peroxidation beside the apoptotic cell formation, using histopathological and immunohistochemical methods in the brain

tissue of 1-month-old male and female New Zealand White rabbits that were exposed to these fields at their mother's womb and after the birth. Oxidative DNA damage and lipid peroxidation levels were investigated by measuring the 8-hydroxy-2'-deoxyguanosine (8-OHdG) and malondialdehyde (MDA) levels, respectively. Histopathological changes were observed using by hematoxylin and eosin (HE) staining. Apoptotic cells were detected in the examined organs by terminal deoxynucleotidyl transferase-mediated dUTP nick end-labeling (TUNEL) staining.

For both male and female infants; 8-OHdG levels increased in the group exposed to RFR in both intrauterine and extrauterine periods compared to the infants that were never exposed to RFR and the ones were exposed when they reached one month of age ($p < 0.05$). MDA results were different for male and female rabbits. There was no difference between all female infant groups ($p > 0.05$), while only intrauterine exposure significantly causes MDA level increase for the male infants. HE staining revealed mild lesions in neuronal necrobiosis in brain tissues of female rabbits that had only intrauterine exposure and male rabbits had only extrauterine exposure. Gliosis were mildly positive in brain tissues of rabbits that are exposed only intrauterine period, also the group exposed both intrauterine and extrauterine periods. However, there was no apoptotic change detected by TUNEL staining in the brain tissues of all groups.

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Çelik, Mehmet Cemal Kahya, Mustafa Nazıroğlu. [Oxidative stress of brain and liver is increased by Wi-Fi \(2.45 GHz\) exposure of rats during pregnancy and the development of newborns](#). Pages 134-139.

Highlights

- Oxidative stress plays important role in biology of Wi-Fi (2.45 GHz)
- 2.45 GHz increased oxidative stress in brain and liver pregnant rats and their newborns
- Brain seems sensitive to oxidative injury in the development of newborns.

Abstract

An excessive production of reactive oxygen substances (ROS) and reduced antioxidant defence systems resulting from electromagnetic radiation (EMR) exposure may lead to oxidative brain and liver damage and degradation of membranes during pregnancy and development of rat pups. We aimed to investigate the effects of Wi-Fi-induced EMR on the brain and liver antioxidant redox systems in the rat during pregnancy and development.

Sixteen pregnant rats and their 48 newborns were equally divided into control and EMR groups. The EMR groups were exposed to 2.45 GHz EMR (1 h/day for 5 days/week) from pregnancy to 3 weeks of age. Brain cortex and liver samples were taken from the newborns between the first and third weeks. In the EMR groups, lipid peroxidation levels in the brain and liver were increased following EMR exposure; however, the glutathione peroxidase (GSH-Px) activity, and vitamin A, vitamin E and β -carotene concentrations were decreased in the brain and liver. Glutathione (GSH) and vitamin C concentrations in the brain were also lower in the EMR groups than in the controls; however, their concentrations did not change in the liver.

In conclusion, Wi-Fi-induced oxidative stress in the brain and liver of developing rats was the result of reduced GSH-Px, GSH and antioxidant vitamin concentrations. Moreover, the brain seemed to be more sensitive to oxidative injury compared to the liver in the development of newborns.